A

Synopsis

On

"Analysis of Kinematical and Dynamical Behaviours of Cosmological Models in Theories of Gravity"

Submitted to

Swami Ramanand Teerth Marathwada University,

Vishnupuri, Nanded-431 606

For the Degree of

Doctor of Philosophy (Ph.D.)

In Mathematics (Faculty of Science &Technology)

Submitted by

Mr. Pramod S. Gaikwad
Research Student,
School of Mathematical Sciences,
SRTM University, Nanded.

Under the Guidance of

Dr. Dnyaneshwar D. Pawar

Professor and Director,
School of Mathematical Sciences,
SRTM University, Nanded.

August 2021.

Title: Analysis of Kinematical and Dynamical Behaviours of Cosmological Models in Theories of Gravity

1. Introduction:

The Cosmic Microwave Background radiation as seen in data from satellites such as the Wilkinson Microwave Anisotropy Probe (Knop et al. 2003) and from observations of Large Scale Structure (Tegmark et al. 2004a, 2004b) of the universe confirmed that the problem of cosmic acceleration one. Basically, two kinds of alternative explanations have been proposed for this unexpected observational phenomenon. One is, the problem lies in detecting an exotic type of unknown repulsive force (an exotic energy with large negative pressure), termed as dark energy which is responsible for the accelerating phase of the Universe and other, by modifying the Einstein equation called Modified Gravity which is of great importance because it can successfully explain the rotation curve of galaxies and the motion of galaxy clusters in the universe.

The detection of dark energy would be a new clue to an old puzzle: the gravitational effect of the zero-point energies of particles and fields (Zel'dovich 1968). The total with other energies, that are close to homogeneous and nearly independent of time, acts as DE. The paramount characteristic of the DE is a constant or slightly changing energy density as the Universe expands, but we do not know the nature of DE very well (Turner and Huterer 2007; Bartelmann 2010). Dark energy has been conventionally characterized by the Equation of State parameter $\omega = p/\rho$, where ω is not necessarily constant. The ω lies close to -1: it would be equal to (standard cosmology), a little bit upper than -1 (the quintessence dark energy) or less than -1 (phantom dark energy). The possibility $\omega << -1$ is ruled out by current cosmological data. Akarsu and Kilinc (2010) have studied locally rotationally symmetric Bianchi type-I cosmological models with a constant deceleration parameter in the presence of anisotropic dark energy and a per fect fluid. They have considered phenomenological parameterization of minimally interacting dark energy in terms of its equation of state parameter and time-dependent skewness parameters. Pawar and Solanke (2014) gives an exact Kantowski-Sachs anisotropic dark energy cosmological models in Brans Dicke theory of gravitation. Pawar et al. (2014) Magnetized dark energy cosmological models with time dependent cosmological term in Lyra geometry. Mahanta et al. (2014) constructed dark energy anisotropic Bianchi type-III cosmological models with a variable equation of state parameter in Barber's second self-creation theory of gravitation using the special law of variation of Hubble's parameter that yields a constant value of the deceleration parameter and obtained two different models in which first model the value of equation of state parameter is in good agreement with the recent observations of type Ia supernovae data with cosmic microwave background radiation anisotropy and galaxy clustering statistics. Recently Aditya et al. (2019) investigated the dark energy phenomenon by studying the Tsallis holographic dark energy within the framework of Brans Dicke scalar–tensor theory of gravity where the Brans and Dicke scalar field is a logarithmic function of the average scale factor and Hubble horizon as the IR cutoff and very recently Singh et al. (2020) examined dark energy cosmological model in modified scale covariant theory of gravitation.

2. Review of Literature and Development in the Subject:

The dynamical dark energy models are classified into two different categories: (i) the scalar fields including Quintessence, Phantom, Quintom, K-essence, Tachyon, Dilaton, and so forth; (ii) the interacting models of dark energy such as the Chaplygin gas models (Sarkar 2014), Agegraphic (Wei and Cai 2008) and Holographic (Thomas 2002; Setare 2007) models. In recent years, an interesting observation is made to determine the nature of dark energy in quantum gravity which is termed as holographic dark energy using principle of holographic dark energy. This principle (the degrees of freedom in a bounded system should be finite and does not scale by it volume but with its boundary era) was first put forwarded by Hooft (1993) in the context of black hole physics. Latter on Fischler and Susskind (1998) have proposed a new version of the holographic principle, viz. at any time during cosmological evolution, the gravitational entropy within a closed surface should not be always larger than the particle entropy that passes through the past light-cone of that surface.

There are various modified gravity, one replaces the Ricci scalar R in the Einstein-Hilbert action by an arbitrary function of R belongs to the well-known f (R) modified gravity (Azadi et al. 2008; Sharif and Yousaf 2014; Chirde and Shekh 2016a, 2017). Another one that has gained much regard in the last few years is Gauss-Bonnet gravity say f (G) theory of gravity (Nojiri and Odintsov 2005, 2007; Cognola et al. 2007; Fayaz et al. 2015; Abbas et al. 2015; Sharif and Fatima 2016) where f (G) is a generic function of the Gauss-Bonnet invariant G. Also the theory which combines Ricci scalar and Gauss-Bonnet scalar called f (R,G) gravity theory (Lvaro and Diego 2012; Shekh and Chirde 2019; Makarenko et al. 2013; Atazadeh and Darabi 2014; Laurentis and Lopez-Revelles 2014; Shekh et al. 2020).

One the gravitational action includes an arbitrary function of the Ricci scalar and trace of the stress energy tensor known as f (R,T) gravity. Several authors such as Sahoo et al. (2014), Chirde and Shekh (2015, 2016b), Agrawal and Pawar (2017) who have investigated the aspects of cosmological models in this gravity. Among the various modifications of Einstein's theory, another one way to look at the theory beyond the Einstein equation is the Teleparallel Gravity (TG) which uses the Weitzenbock connection in place of the Levi–Civita connection and so it has no curvature but has torsion which is responsible for the acceleration of the Universe. Some relevant works in this gravity are the graphical representation of k-essence with the help of equation of state parameter describe by Sharif and Rani (2011). In f (T) gravity the existence of relativistic stars investigated by Bohmer et al. (2011). Chirde and Shekh (2014) have discussed some cosmological model with different sources. Gamal and Nashed (2015) investigated anisotropic models with two fluids in linear and quadratic forms of f (T) gravitational models. Recently, Bhoyar et al. (2017) discussed stability of accelerating Universe with linear equation of state parameter in f (T) gravity using hybrid expansion law.

Bianchi type cosmological models are significant in the sense that these are homogeneous and anisotropic. Bianchi type space times provide spatially homogeneous and anisotropic models of the universe as compared to the homogeneous and isotropic FRW models, from which the course of action of isotropization of the universe is well thought-out the passage of time. The simplicity of the field equations and relative ease of the solutions of Bianchi space

times are useful in constructing models of spatially homogeneous and anisotropic cosmologies. Spatially homogeneous and anisotropic cosmological models play a significant role in the description of large scale behavior of the universe and such models have been widely studied many authors in search of relativistic picture of the early universe. Mohanty et al. (2003), Pradhan et al. (2011), Kumar and Yadav (2011), Yadav and Saha (2012) are the some authors who have been extensively investigated an anisotropic Bianchi type-I, Bianchi type-III, Bianchi type-V dark energy models with the usual perfect fluid. Recently, Sarkar and Mahanta (2013) have studied a homogeneous and anisotropic axially symmetric Bianchi type-I universe filled with matter and holographic dark energy components by assuming deceleration parameter to be a constant, along with the correspondence between the holographic dark energy models with the quintessence dark energy and reconstruction of the Quintessence potential and the dynamics of the quintessence scalar field in an accelerated expansion of the universe. Mishra et al. (2017) who have investigated the anisotropic behavior of the accelerating universe with the matter field of two non-interacting fluids usual string fluid and dark energy fluid and achieve a physically reasonable clarification using hybrid scale factor, which is generated by a time-varying deceleration parameter and observed that the string fluid dominates the universe at early deceleration phase but does not influence nature of cosmic dynamics significantly at late phase, whereas the dark energy fluid dominates the universe in present time, which is in accordance with the observations results. Chirde and Shekh (2018a, 2018b) have investigated the dynamics of Bianchi type-I space–time filled with two minimally interacting fields, Matter and Holographic dark energy components with volumetric power and exponential expansion laws and the transition between general relativity and quantum gravity using quark and strange quark matter respectively towards the gravitational field equations for the linear form of f (T) gravity and observed that both models are at late times turn out to be flat Universe, the power law model has to begin with singular and stable but at spreading out it is unstable while exponential model is free from any types of singularities and stable throughout the expansion. In the same way the models represents its spreading as accelerated with inflationary era in the early and the very late time of the Universe. For suitably large time resulting model expects that the anisotropy of the Universe will damp out and the Universe will become isotropic. Very recently, Pawar et al. (2019) the author who have studied the modified holographic Ricci dark energy model in f (R,T) theory of gravity by using anisotropy Bianchi type Universe and observed that the model has no physical singularity, the Universe is expanding and accelerating exponentially.

3. Aim and Objectives of Research:

We will discuss the latest observations of the kinematics of stars in these systems. We tour through the various dynamical techniques used, with emphasis on the complementarily limitations, and discuss what the results imply also in the context of cosmological models. We will discuss the kinematical and dynamical behaviours of cosmological model. Considering all types of space-times including Bianchi types, Plane symmetric, Kantowski-Sachs FRW space time and Kasner space-times, we will obtain the exact solutions of the Einstein's field equations, with perfect fluid, dark energy and dark matter. Some physical and geometrical properties of the models will be studied.

4. Methodology:

Knowledge of the concern topic will be obtained by the survey of research papers, review articles, various books and journals. Also we would like to visit different research institutes like TIFR, IUCAA Pune, IIT, IISC, BHU Varanasi, SGB Uni. Amravati, RTM Uni. Nagpur etc to interact with eminent Mathematicians and Physicist also would like to attend national, international conference related to our research work.

5. Importance of Study:

In this work we analyze kinematical and Dynamical behaviours of cosmological models based on theories of gravity. The evolution of the universe seems to be dominated by a mysterious form of energy, dark energy. A true cosmological constant can act as dark energy. However, this constant has a difficult theoretical interpretation and suffers the fine-tuning problem. Besides it gives no solution for the coincidence problem. However, do we need a fundamental solution for dark energy dominance now? Assuming that the coincidence problem has a solution, a dynamical mechanism for dark energy is a good candidate. Since it seems that about 70% of the energy of the universe is not under-stood, the nature of dark energy is one of the most exciting and fundamental question of physics today. The main purpose of the present work is to study the dynamical and physical behaviour of dark energy in the evolution of universe; it will be useful for young researchers. Finally we provide an outlook on exciting developments in this field.

6. Plan of Research Work:

Sr.No	**Period**	**Plan of the work**	**Targets to be achieved**
1	First year	Study of the background required for the research topic.	Good command on the subject and clear the course work.
2	Second year	Collecting the papers and analyze them.	Try to get some Construction techniques.
3	Third Year	Work on some problems to be included in the thesis.	Submit at least two papers.
4	Fourth Year	Publishing some papers and submitting the Thesis.	Some more papers and Thesis submission.

7. References:

1. Abbas, G., Momeni, D., Ali, M.A., Myrzakulov, R., Qaisar, S.: Astrophys. Space Sci. 357, 158 (2015)
2. Aditya, Y., Mandal, S., Sahoo, P.K., Reddy, D.R.K.: Eur. Phys. J. C 79(12), 1020 (2019)
3. Agrawal, P.K., Pawar, D.D.: New Astron. 54, 56 (2017)
4. Akarsu, O., Kilinc, C.B.: Astrophys. Space Sci. 326, 315 (2010)
5. Atazadeh, K., Darabi, F.: Gen. Relativ. Gravit. 46, 1664 (2014)
6. Azadi, A., Momeni, D., Nouri-Zonoz, M.: Phys. Lett. B 670, 210 (2008)
7. Bartelmann, M.: Rev. Mod. Phys. 82, 331 (2010)
8. Bhoyar, S.R., Chirde, V.R., Shekh, S.H.: Astrophysics 60, 277 (2017)
9. Bohmer, C., Mussa, A., Tamanini, N.: Class. Quantum Gravity 28, 245020 (2011)
10. Chirde, V.R., Shekh, S.H.: Bulg. J. Phys. 41, 258 (2014)
11. Chirde, V.R., Shekh, S.H.: Astrophysics 58, 106 (2015). https://doi. org/10.1007/s10511-015-9369-6 Chirde, V.R., Shekh, S.H.: Bulg. J. Phys. 43, 57 (2016a)
12. Chirde, V.R., Shekh, S.H.: J. Astrophys. Astron. 37, 15 (2016b)
13. Chirde, V.R., Shekh, S.H.: J. Theor. Phys. Cryptogr. 13, 14 (2017)
14. Chirde, V.R., Shekh, S.H.: J. Astrophys. Astron. 39, 56 (2018b)
15. Cognola, G., Elizalde, E., Nojiri, S., Odintsov, S.D., Zerbini, S.: Phys. Rev. D 75, 086002 (2007)
16. Fayaz, V., Hossienkhani, H., Mohammadi, A.: Astrophys. Space Sci. 357, 136 (2015)
17. Fischler, W., Susskind, L.: hep-th/9806039 (1998)
18. Gamal, G., Nashed: Astrophys. Space Sci. 357, 111 (2015)
19. Granda, L.N., Oliveros, A.: Phys. Lett. B 669, 275 (2008)
20. Hooft, G.: gr-qc/9310026 (1993)
21. Knop, R.A., et al.: Astrophys. J. 598, 102 (2003)
22. Kumar, S., Yadav, A.K.: Mod. Phys. Lett. A 26, 647 (2011)
23. Laurentis, M.D., Lopez-Revelles, A.J.: Int. J. Geom. Methods Mod. Phys. 11, 1450078 (2014) Lvaro, De.C., Diego, S.G.: Class. Quantum Gravity 29, 24 (2012)
24. Mahanta, K.L., Biswal, A.K., Sahoo, P.K.: Can. J. Phys. 92(4), 295 (2014)
25. Makarenko, A.N., Obukhov, V.V., Kirnos, I.V.: Astrophys. Space Sci. 343, 481 (2013)
26. Mishra, B., Sahoo, P.K., Ray, P.P.: Int. J. Geom. Methods Mod. Phys. 14(9), 1750124 (2017) Mohanty, G., Sahu, S.K., Sahoo, P.K.: Astrophys. Space Sci. 288, 523 (2003)
27. Nojiri, S., Odintsov, S.D.: Phys. Lett. B 631, 1 (2005)
28. Nojiri, S., Odintsov, S.D.: J. Phys. Conf. Ser. 66, 012005 (2007)
29. Pawar, D.D., Solanke, Y.S.: Int. J. Theor. Phys. 53(9), 3052 (2014)
30. Pawar, D.D., Solanke, Y.S., Shahare, S.P.: Bulg. J. Phys. 41, 60 (2014)
31. Pawar, D.D., Mapari, R.V., Agrawal, P.K.: J. Astrophys. Astron. 40, 13 (2019)
32. Pradhan, A., et al.: Int. J. Theor. Phys. 50, 2923 (2011)
33. Sahoo, P., Mishra, B., Chakradhar, G., Reddy, D.: Eur. Phys. J. Plus 129, 49 (2014)
34. Sarkar, S.: Astrophys. Space Sci. 349, 985 (2014)
35. Sarkar, s., Mahanta, C.R.: Int. J. Theor. Phys. 52(5), 1482 (2013)

36. Setare, M.R.: Phys. Lett. B 653, 116 (2007)
37. Sharif, M., Fatima, H.I.: Int. J. Mod. Phys. D 25, 1650011 (2016)
38. Sharif, M., Rani, S.: Phys. Scr. 84, 055005 (2011)
39. Sharif, M., Yousaf, Z.: J. Cosmol. Astropart. Phys. 6, 19 (2014)
40. Shekh, S.H., Chirde, V.R.: Gen. Relativ. Gravit. 51, 87 (2019)
41. Shekh, S.H., Arora Simran, Chirde, V.R., Sahoo, P.K.: Int. J. Geom. Methods Mod. Phys. (2020). https://doi.org/10.1142/ S0219887820500486
42. Singh, K.M., Mandal, S., Devi, L.P., Sahoo, P.K.: New Astron. 77(12), 101353 (2020)
43. Tegmark, M., et al.: Phys. Rev. D 69, 103501 (2004a)
44. Tegmark, M., Blanton, M.R., Strauss, M.A.: Astrophys. J. 606(2), 702 (2004b)
45. Thomas, S.: Phys. Rev. Lett. 89, 081301 (2002)
46. Turner, M.S., Huterer, D.: J. Phys. Soc. Jpn. 76, 111015 (2007)
47. Wei, H., Cai, R.: Phys. Lett. B 660, 113 (2008)
48. Yadav, A.K., Saha, B.: Astrophys. Space Sci. 337, 759 (2012)
49. Zel'dovich, Y.B.: Sov. Phys. Usp. 11, 381 (1968)

Mr. Pramod S. Gaikwad
Research Scholar

Dr. D. D. Pawar
Research Guide